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Abstract

Using existing data from untreated research plots, we developed an equation for predicting 5-yr diameter-growth rate (ΔD_5) for western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] in the coastal region of the Pacific Northwest. This equation is a revision of the equation constructed in 1995–1997 for the Stand Management Cooperative's (SMC) version of the ORGANON growth-and-yield model, and it has been developed with substantially larger and more comprehensive data sets than were available in 1995–1997. The effects of the new equation on stand-level predictions were evaluated by comparing the maximum mean annual increments (*MAI*) in total stem volume (ft^3) and associated rotation ages (*RA*) predicted from the original SMC-ORGANON model and the northwest Oregon version of ORGANON (NWO-ORGANON) to predictions from the revised SMC-ORGANON model. This analysis was done by making 150-yr projections using 36 plots in young stands from the SMC data sets. On average, the revised model without using a limit on the maximum SDI increased *RA* by 9.0 yr (or an average percent increase of 12.0) and reduced the maximum *MAI* by 56.7 ft^3/ac/yr (or an average percent reduction of 13.2) when compared to the original SMC-ORGANON, and it reduced RA by 9.0 yr (or a average percent reduction of 10.3) and maximum MAI by 0.0 ft^3/ac/yr (or an average percent increase of 1.8) when compared to NWO-ORGANON. When using a limit on the maximum SDI, the revised SMC-ORGANON model, on average, increased *RA* by 10.3 yr (or an average percent increase of 15.0) and reduced the maximum *MAI* by 33.6 ft^3/ac/yr (or and average percent reduction of 8.8) when compared to the original SMC-ORGANON, and it reduced RA by 4.4 yr (or an average percent reduction of 5.2) and increased maximum MAI by 8.7 ft^3/ac/yr (or and average percent increase of 4.4) when compared to NWO-ORGANON.

Keywords: Growth-and-yield model, stand development, Stand Management Cooperative

Introduction

The equation developed for predicting the 5-yr diameter growth rate (ΔD_5) of western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] in the Stand Management Cooperative (SMC; Chappell and Osawa 1991) version of ORGANON (SMC-ORGANON; Hann et al. 1997) was completed in 1997. Because of several data problems, measurements from the SMC Type I and Type III installations were not included in the development of these equations (Hann et al. 2003, 2006). Since the original SMC-ORGANON equations were created the subsequent 12 yr have allowed for additional plot establishment, remeasurements, and growth. Given this development, we decided to reanalyze the ΔD_5 equation for western hemlock in order to better characterize its values in young plantations. The resulting new equation is to be inserted into a revised version of SMC-ORGANON and tested against both the original version and the NWO-ORGANON version.

Data Description

This analysis utilized six data sets. Three came from the SMC, and three from data collected in previous ORGANON modeling work. Basic tree measurements needed to model ΔD_5 include diameter at breast height (D), total height (H), height to crown base (HCB), and the expansion factor (EF) for each sample tree at each measurement. The EF is the number of trees per acre (tpa) that each sample tree represents. Tree and plot attributes measured at the start of the growth period (denoted by a subscript of "S") that have previously been used to predict ΔD_5 (Hann et al. 2003) include the SI of the installation, the basal area per acre of the plot (BA_S), the D_S and crown ratio (CR_S) of the tree, and the BA/ac in trees with D_S larger than the subject tree on the plot (BAL_S).

Data from SMC Cooperators

The first SMC data set selected for this analysis was part of the data used to develop the original version of SMC-ORGANON. All of the data donated by the SMC cooperators came from untreated permanent plots in even-aged western hemlock stands on public and private ownerships throughout southwestern British Columbia, western Washington, and northwestern Oregon. The 7 installations containing these plots were originally established in both plantations and natural stands to explore a variety of silvicultural objectives. Plot sizes ranged from 0.05 to 1.0 ac, with the 0.2-ac plot being most common. This ΔD_5 data set is described fully by Hann et al. (2003).

Data from SMC Installations

The Type I, and III installations of the SMC that had been established in pure western hemlock plantations were also used in this analysis. Total age (TA) at establishment ranged from 11 to 18 yr on the 8 Type I installations, and from 5 to 8 yr on the 4 Type III installations. The Type I installations each contained a single control plot of 0.5 ac. The Type III installations contained one control plot in each of the six planting densities (100, 200, 300, 440, 680, and 1,210 tpa) on an installation. Plot sizes on the Type III installations ranged from 0.496 ac for the 100-tpa planting density to 0.212 ac for the 1,210-tpa density. The remeasurement interval was 4 yr for the Type I installations and either 2 or 4 yr for the Type III installations. Total length of measurements ranged from 6 to 16 yr. *H* and *HCB* were subsampled on all of the SMC installations.

The calculation of top height (*H40*) requires estimates of *H* for all larger trees on the plot. To fill in *H*, the following equation form was used to characterize the height-diameter relationship for the measured values of *H* and *D* for each measurement on each plot:

$$H = 4.5 + e^{a_0 + a_1 D^{-1}} \quad [1]$$

The parameters a_0 and a_1 of Eq. [1] were estimated by taking the logarithms of both sides of the equation and fitting the resulting log-log equation to the data with linear regression. Examination of the sizes of the resulting mean squared errors (MSEs) for these fits indicated that correction for log bias was unnecessary. Predictions from Eq. [1] were then used to estimate H on larger trees without direct measurements.

Two methods of measuring *HCB* have been used extensively in the Pacific Northwest. In the first method, the lower branches on the longer side of the crown of trees of uneven crown length are transferred mentally to fill in the missing portion of the shorter side of the crown. The objective of this method is to generate a "full, even crown". *HCB* is then measured to this mentally generated position on the bole (epicormic and short internodal branches are ignored). This method is used in the ORGANON model.

In the second method, crown base is defined as the lowest whorl with live branches in at least three quadrants around the stem circumference. Again, epicormic branches and whorls not continuous with the main crown are ignored. The *HCB* by this method ($HCB_{3/4}$) is the distance from the ground to the whorl defining this crown base. Maguire and Hann (1987) showed that $HCB_{3/4}$ was greater than or equal to *HCB*. Because $HCB_{3/4}$ is the method used in the SMC installation data sets, the equation of Johnson (2002) was used to convert $HCB_{3/4}$ to *HCB*. This conversion equation predicts very small differences between $\mathrm{HCB}_{3/4}$ and HCB for trees with very large CR. Therefore, the correction was small for the young, long-crowned trees in the Type I and III data sets.

For trees with measured *H* and *HCB*, crown length (*CL*) for each tree and measurement was calculated by subtracting *HCB* from *H*. The *CR* was then computed by dividing *CL* by *H*. The *EF* for each sample tree was calculated by taking the reciprocal of the plot area (ac).

Breast height age (*BHA*) at the last measurement was needed to calculate site indices for the SMC Type I and III control plots. *BHA* is defined as the average number of growing seasons completed by the top height trees (i.e., the 40 largest diameter trees) on the plot after the trees had reached 4.5 ft in height. Because a tree could reach 4.5 ft in height during a growing season, it is not unusual for BHA to be continuous, rather than integer, numbers. The recognition and correct measurement of fractional *BHA* is particularly critical in the calculation of *SI* in very young stands. For each plot, *BHA* was computed as the average *BHA* from increment cores or whorl counts of those trees with *D* at least as large as the minimum *D* of the top height trees at the last measurement. *H40* for each measurement on each control plot was computed by averaging the heights of the 40 largest diameter trees per acre on the plot. Finally, Bonner's et al (1995) *SI* was computed for each plot using the *H40* and *BHA* for the most recent measurement on the plot.

ORGANON uses a 5-yr growth period. Therefore, the interpolation procedures described by Hann et al. (2003) were used to obtain the necessary 5-yr measurements of ΔD_5. All possible consecutive 5-yr growth periods were produced for each sample tree, beginning with the first measurement where $D > 0$. Because each 5-yr growth period was required to start with an actual measurement (i.e., not interpolated values) and the usage of even growth measurement intervals, it was sometimes necessary to overlap the resulting consecutive growth periods. The amount of overlap was limited to 1 yr where this was necessary. Only one of the consecutive growth periods, randomly selected from each tree, was used in the final ΔD_5 modeling data sets.

ORGANON Data Sets

The ΔD_5 analysis of Hann and Hanus (2002) showed that the model's predictive behavior could be substantially improved by including larger diameter trees in the analysis. Because the SMC data sets did not contain very large trees, we decided to conduct a giant size regression (Cunia 1973) analysis by including the data from three ORGANON modeling projects in the development of the new SMC ΔD_5 equation. The three ORGANON ΔD_5 studies of western hemlock used backdating of temporary plots to collect the modeling data. The southwest

Oregon study sampled 35 plots containing western hemlock (Hann and Hanus 2002). Plots ranged from even-aged to uneven-aged in structure and from pure to mixed species in composition. The northwest Oregon study sampled 43 plots on the old Willamette Industries lands along the coast of Oregon (Johnson 2002). Plots were even-aged in structure with at least 80% of their basal area in western hemlock. The western Washington study sampled 34 plots (McKenzie 1994). Plots were predominantly two-tiered in structure and composed primarily of Douglas-fir and western hemlock.

In all three studies, each plot was composed of a minimum of four sample points spaced 150 ft apart. The sampling grid was established so that all sample points were at least 100 ft from the edge of the stand. At each sample point, trees were sampled with a nested plot design composed of four subplots: trees with $D \leq 4.0$ in. were selected on a 1/229-ac fixed-area subplot, trees with $D = 4.1–8.0$ in. were selected on a 1/57-ac fixed-area subplot, and trees with $D > 8.0$ in. were selected on a 20 basal area factor (BAF) variable-radius subplot. For the southwest Oregon study, trees with $D > 36.0$ in. were selected on a 60-BAF variable-radius subplot.

Measurements of D, H, and HCB at the end of the growth period were taken on all sample trees in all three data sets. Backdating procedures for calculating D_S, H_S, HCB_S, and EF_S are described in Hann and Hanus (2001). Procedures for calculating SI, BA_S, and BAL_S are described in Hann and Hanus (2002) for the southwest Oregon data set, in Johnson (2002) for the northwest Oregon data set, and in McKenzie (1994) for the western Washington data set. Hann and Scrivani's (1987) Douglas-fir SI was used in the southwestern Oregon data set, and it was converted to an estimate of western hemlock site index using the conversion equation of Nigh (1995). Bonner's et al. (1995) SI was used in the northwest Oregon and western Washington's data sets.

Data Analysis

The first step of the analysis applied the original control plot equation of Hann et al. (2003) to the data from the SMC Type I and III installations and computed the residuals of actual ΔD_5 minus predicted ΔD_5 (PredΔD_5). The data used in this and subsequent ΔD_5 analyses were restricted to observations with an actual measurement of CR_S. Negative values of ΔD_5 were treated as measurement errors and they were removed from all analyses. The residuals were then plotted over PredΔD_5, D_S, CR_S, SI_B, BA_S and BAL_S and evaluated for trends. These graphs indicated that the original equation under predicted ΔD_5 for trees with small diameters and that the under prediction was most severe in the SMC Type III installations.

Hann and Hanus (2002) and Hann et al. (2006) found that having a modeling data set which ranged across the full range of tree sizes was critical to the accurate and precise modeling of tree dynamics. Unfortunately, the data from the SMC cooperators and the SMC installations alone do not contain trees with large *D*. As Hann et al. (2006) did in their analysis, we decided to include the ΔD_5 modeling data sets from the three ORGANON projects to ameliorate this problem.

In incorporating the ORGANON data, it was assumed that the relationship of ΔD_5 to D_S and CR_S was the same across all of the modeling data sets. Six indicator variables were therefore included to recognize differences in how, where, and when the data were collected. These additional variables identified that (1) *SI* estimated for the southwest Oregon data differed from *SI* used in all of the other data sets, (2) the calculated values of BA_S and BAL_S could be affected by the substantial difference between the ORGANON plot design and the plot design in the SMC data sets (Hann and Zumrawi 1991), and (3) the three ORGANON modeling data sets were collected over relatively short periods on temporary plots in different parts of the Pacific Northwest.

The resulting model form allowed for larger predictions of ΔD_5 for trees with small D and it was also more effective at characterizing the ΔD_5 of trees with very large D:

$$\Delta D_5 = e^{\sum_{i=0}^{12} b_i X_i} + \varepsilon_{\Delta D} \quad [2]$$

where

$X_0 = 1.0$

$X_1 = \ln(D_S + 5)$

$X_2 = D_S$

$X_3 = \ln[(CR_s + 0.2)/1.2]$

$X_4 = \{1.0 - I_{SWO}\}\ln(SI - 4.5)$

$X_5 = SBAL_S/[\ln(D_S + 2.7)]$

$X_6 = SBA_S^{1/2}$

$X_7 = I_{SWO}$

$X_8 = I_{NWO}$

$X_9 = I_{WWA}$

$X_{10} = I_{SWO} \ln(SI - 4.5)$

$X_{11} = \{I_{ORG}\}\{SBAL_S/[\ln(D_S + 2.7]\}$

$X_{12} = (I_{ORG})(SBA_S^{1/2})$

I_{SWO} = 1.0 if data came from the SWO-ORGANON data set, = 0.0 otherwise.

I_{NWO} = 1.0 if data came from the NWO-ORGANON data set, = 0.0 otherwise.

I_{WWA} = 1.0 if data came from the WWA-ORGANON data set, = 0.0 otherwise.

$I_{ORG} = I_{SWO} + I_{NWO} + I_{WWA}$

b_i = regression parameter for i^{th} variable

$\varepsilon_{\Delta D}$ = random error on ΔD_5

Applying the procedures described in Kmenta (1986) and Hann and Larsen (1991), we estimated the parameters of Eq. [2], (i.e., b_i), by weighted nonlinear regression with a weight of the reciprocal of $Pred\Delta D_5$, using the ΔD_5 modeling data set described in Table 1. As a check of the equation, both the weighted and the unweighted residuals were examined for systematic trends across $Pred\Delta D_5$ and the independent variables. The mean unweighted residual, the standard deviation of the unweighted residuals, and the adjusted coefficient of determination (R_a^2) of the unweighted residuals were also calculated. This residual analysis was done for the combined data set and for each of the seven component data sets.

The following procedures were then used to evaluate the impact of the new ΔD equation on stand-level predictions from the SMC-ORGANON model:

1. Data from the SMC Type I and III installations were used to create 36 input tree lists needed to run the ORGANON model (Hann et al. 1997). For each untreated plot on an installation, the first measurement in which all trees on the plot had reached at least 4.5 ft in height was selected for creation of the only input tree list used for that plot.
2. A new variant of the SMC-ORGANON model was created by replacing the original ΔD equation with the new equation.
3. Six 150-yr projections were made on each of the 36 input tree lists. The following three runs were made with the optional “limit on maximum SDI” turned off (see Hann et al. 1997 for a description of this option): (1) original SMC-ORGANON, (2) NWO-ORGANON, and (3) the new variant of SMC-ORGANON. Finally, the same runs were made with the optional “limit on maximum SDI” turned on.
4. For each growth projection on each tree list, the following values were plotted across stand age and the trends examined for reasonableness of behavior: *BA*, *TPA*, total stem cubic foot volume per acre (*TSCFV*), the mean annual increment (*MAI*) of *TSCFV*, the periodic annual increment of *TSCFV*, average *CR*, and *SDI*.

5. The maximum *MAI* and the associated rotation age based on maximizing *MAI* were then extracted from each run's output file. These values were then used to calculate both the difference of new variant of SMC-ORGANON minus the original SMC-ORGANON value or the NWO-ORGQNON value, and a percent difference, by dividing the difference by either the original SMC-ORGANON value or the NWO-ORGANON value and multiplying by 100. Finally, the mean, minimum, maximum, and standard deviation of the 36 difference values and 36 percent-difference values associated with each of the two comparisons were computed and tabulated.

Results and Discussion

Table 2 contains the parameter estimates and associated standard errors for Eq. [2]. Graphs of both the weighted and the unweighted residuals across $Pred\Delta D_5$ and the independent variables for both the combined data set and each of the five component data sets showed no marked trends. Therefore, the trends in the residuals found in this study for the ΔD_5 equation of Hann et al. (2003) have been removed.

The mean unweighted residual, the standard deviation of the unweighted residuals, and the R_a^2 of the unweighted residuals for the combined data set and each of the seven component data sets are shown in Table 3. Equation [2] explains 70% of the overall unweighted variation in ΔD_5, and the mean unweighted residuals are inconsequential for all divisions of the data.

Predicted maximum ΔD_5 and the D_S where the peak occurs can be calculated by setting $CR_S = 1.0$, $BAL_S = 0.0$, $BA_S = 0.005454154 D_S^2$, and SI to a value of interest (Hann and Hanus 2002). For $SI = 115$ (approximately the average for the modeling data set), Eq. [2] predicts a maximum ΔD_5 of 3.77 in. that occurs at $D_S = 10.8$ in., whereas the equation of Hann et al. (2003) predicts a maximum ΔD_5 of 2.78 in. that occurs at $D_S = 8.2$ in. and the equation of Johnson (2002) predicts a maximum ΔD_5 of 4.32 in. that occurs at $D_S = 9.8$ in.. Therefore, the new western hemlock equation has a peak that occurs closer to the value of D_S = 13.6 in. for the new Douglas-fir equation of Hann et al. (2006) than the previous western hemlock equations. Given that both species can achieve very large values of D, we believe that the larger D for the peak is an improvement over the previous equations.

Equation [2] also predicts values of ΔD_5 that are substantially larger than the predictions from the equation of Hann et al. (2003) or the equation of Johnson (2002) for small values of $D_{S,}$ which eliminated the trend in the residuals found for the previous equations. Finally, the equations of Hann et al. (2003) and Johnson (2002) both predict that maximum ΔD_5 become practically zero for trees with a 50 in. to 60 in. *D*, which is unrealistic given that *D* values as large as 113” have been reported for western hemlock (Hardin et al. 2001). Equation [2], on the other hand, predicts a maximum ΔD_5 of 1.87 in for a tree with a *D* of 60 in., which may be too optimistic for a tree of that size. We conclude that future fits of the western hemlock ΔD_5 equation would benefit from having measurements from more stands with very large *D*.

The incorporation of Eq. [2] into SMC-ORGANON and choosing not to use ORGANON’s limit on maximum SDI resulted in an average increase of 9.0 yr (or an average percent increase of 12.0) in the predicted RA that would maximize the production of total stem cubic foot volume per acre when compared to the old SMC-ORGANON (Table 4). This comparison produced a reduction in maximum *MAI* by an average of 56.7 ft^3/ac/yr (or an average percent reduction of 13.2, Table 5). Choosing not to use ORGANON’s limit on maximum *SDI* in comparisons with NWO-ORGANON resulted in an average reduction of 9.0 yr (or an average percent reduction of 10.3) in the predicted RA (Table 4), and an average reduction of 0.0 ft^3/ac/yr (or an average percent increase of 1.8) in predicted maximum MAI (Table 5).

Using ORGANON’s limit on maximum *SDI* resulted in an average increase of 10.3 yr (or an average percent increase of 15.0) in the predicted *RA* that would maximize the production of total stem cubic foot volume per acre when compared to the old SMC-ORGANON (Table 6). This comparison produced a reduction in maximum *MAI* by an overage of 33.6 ft^3/ac/yr (or a percent average reduction of 8.8, Table 7). Choosing to use ORGANON's limit on maximum *SDI* in comparisons with NWO-ORGANON resulted in an average reduction of 4.4 yr (or an average percent reduction of 5.2) in the predicted RA (Table 6), and an average increase of 8.7 ft^3/ac/yr (or an average percent increase of 4.4) in predicted maximum MAI, (Table 7).

Like the results from the reanalysis of the Douglas-fir SMC equations (Hann et al. 2006), the new ΔD_5 equation for western hemlock reduces the size of the average maximum MAI when compared to the original SMC equation, and the magnitude of the reduction is greater when ORGANON's limit on maximum *SDI* is not used. Also, both analyses produced equations that predicted larger growth in BA very early in the stands' development. Unlike the previous Douglas-fir reanalysis, the new western hemlock equation increases average rotation length when compared to the original SMC equation.

The maximum MAI predictions from the new SMC ORGANON model are much closer to the NWO-ORGANON values than the old SMC-ORGANON values. This is particularly true when the limit on maximum *SDI* is not used. The average RA from the new SMC model is shorter than the values from the NWO model, placing them between the original SMC model's values and the NWO model values.

The results of this analysis indicate to us that the new ΔD_5 equation for western hemlock is an improvement over the original equation. By combining all of the high quality data sets available for western hemlock, we were able to increase the size of the modeling data set from 881 trees to 4,084 trees. However, this increased sample size is still small in relation to the more than 33,000 observations used in the reanalysis of the Douglas-fir ΔD_5 equation (Hann et al. 2006). Trees with very large Ds are particularly lacking in the western hemlock data set. While most landowners will not manage stands to achieve such large trees, the results of this analysis and the previous analyses of Hann and Hanus (2002) and Hann et al. (2006) have shown that the presence of very large trees in the modeling data set can substantially improve the quality of the resulting equation across all size classes.

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Table 1. Sample size and summary statistics, expressed as mean (range), for the ΔD_5 data, by data source

Variable	**SMC cooperators**	**SMC installations**	**ORGANON**
Trees (*n*)	881	1,128	2,075
ΔD_S	1.79	2.0	0.9
	(0.0-4.0)	(0.0-4.2)	(0.1-4.3)
D_S	3.4	3.5	14.3
	(0.1-14.3)	(0.4-13.9)	(0.6-65.7)
CR_S	0.71	0.88	0.51
	(0.11-0.92)	(0.54-0.99)	(0.01-1.00)
BAL_S	41.5	28.5	138.2
	(0.0-280.2)	(0.0-126.4)	(0.0-555.5)
BA_S	74.8	43.6	240.4
	(11.6-325.3)	(5.6-128.1)	(29.4-558.2)
SI	120.1	114.9	109.4
	(91.4-123.6)	(101.2-137.5)	(64.3-160.8)

Table 2. Parameter estimates and asymptotic standard errors (SE) for predicting the 5-yr diameter-growth rate (ΔD_5) of western hemlock, Eq. [2].

Parameter	**Estimate**	**SE**
b_0	-4.87447412	0.30420567
b_1	0.41507232	0.08041560
b_2	-0.02374500	0.00439304
b_3	0.90783730	0.04454163
b_4	1.13467670	0.06125609
b_5	-0.01533350	0.00085365
b_6	-0.03309787	0.00574499
b_7	N.S.	N.S.
b_8	0.26869675	0.06971867
b_9	-0.22823656	0.07825025
b_{10}	1.07982040	0.06835013
b_{11}	0.01378901	0.00085651
b_{12}	-0.03276461	0.00636860

Table 3. Mean, standard deviation (SD), and adjusted coefficient of determination (R_a^2) of the unweighted residuals for the ΔD_5 Eq. [2] by the component modeling data sets.

Data set	**Observations (*n*)**	**Mean**	**SD**	R_a^2
SMC Installations	1,128	-0.045	0.5133	0.5515
SMC Cooperators	881	0.058	0.4051	0.7246
ORGANON	2,075	-0.000	0.5069	0.4566
All	4,084	0.000	0.4898	0.7018

Table 4. Comparisons of predicted rotation ages between the new variant of SMC-ORGANON and both the old variant of SMC-ORGANON and NWO-ORGANON with limit on maximum SDI turned off.

Attribute	Old SMC	NWO	New SMC	New-Old	New-NWO
Rotation Age					
Average	74.8	92.9	83.9		
Minimum	47	57	47		
Maximum	116	131	136		
Change					
Average				9.0	-9.0
Minimum				0	-20
Maximum				20	5
%Change					
Average				12.0	-10.3
Minimum				0	-22.5
Maximum				20.4	3.8

Table 5. Comparisons of predicted total stem cubic foot volume maximum mean annual increments (*MAI*) between the new variant of SMC-ORGANON and both the old variant of SMC-ORGANON and NWO-ORGANON with limit on maximum SDI turned off.

Attribute	Old SMC	NWO	New SMC	New-Old	New-NWO
Maximum MAI					
Average	358.7	302.0	301.9		
Minimum	98.5	95.1	129.0		
Maximum	573.7	456.2	440.5		
Change					
Average				-56.7	-0.0
Minimum				-133.2	-46.0
Maximum				35.5	39.7
%Change					
Average				-13.2	1.8
Minimum				-25.1	-12.5
Maximum				31.0	35.6

Table 6. Comparisons of predicted rotation ages between the new variant of SMC-ORGANON and both the old variant of SMC-ORGANON and NWO-ORGANON with limit on maximum SDI turned on.

Attribute	Old SMC	NWO	New SMC	New-Old	New-NWO
Rotation Age					
Average	70.6	85.4	80.9		
Minimum	42	47	47		
Maximum	116	131	136		
Change					
Average				10.3	-4.4
Minimum				0	-15
Maximum				20	10
%Change					
Average				15.0	-5.2
Minimum				0	-17.9
Maximum				36.4	14.9

Table 7. Comparisons of predicted total stem cubic foot volume maximum mean annual increments (*MAI*) between the new variant of SMC-ORGANON and both the old variant of SMC-ORGANON and NWO-ORGANON with limit on maximum SDI turned on.

Attribute	**Old SMC**	**NWO**	**New SMC**	**New-Old**	**New-NWO**
Maximum MAI					
Average	328.8	286.5	295.2		
Minimum	98.5	95.1	129.0		
Maximum	470.6	414.8	418.2		
Change					
Average				-33.6	8.7
Minimum				-57.6	-31.9
Maximum				30.5	37.8
%Change					
Average				-8.8	4.4
Minimum				-15.7	-8.8
Maximum				31.0	35.6

Appendix: Summary of Abbreviations and Variable Definitions

Abbreviation or variable	Units	Explanation
BA	ft^2/ac	Basal area of the plot
BAF	$ft^2/ac/tree$	Basal area factor
BAL	ft^2/ac	Plot basal area in trees with D >that of the subject tree
BHA	yr	Breast height age: the average number of growing seasons completed by the top height trees (the 40 largest diameter trees) on the plot after the trees had reached 4.5 ft in height.
CL	ft	Length of the live crown (*H* - *HCB*)
CR	none	Live crown ratio (*CL*:*H*)
D	in.	Diameter at 4.5 ft above ground level (breast height)
ΔD_5	in.	5-yr diameter increment
EF	no./ac	Expansion factor: the number of trees/ac represented by the sampled tree
H	ft	Total tree height from ground level to the top of the tree
HCB	ft	Height to a crown base defined as the base of the compacted crown
$HCB_{3/4}$	ft	Height to a crown base defined as the lowest whorl with live branches in at least three quadrants around the stem circumference
H40	ft	The average total tree height for the 40 largest diameter trees/ac

MAI	ft^3/ac/yr	Mean annual increment
RA	yr	Rotation age
SDI	Equivalent no. of 10 in. trees/ac	Reineke’s (1933) stand-density index
SI	ft at 50 yr BHA	Site index
SMC	none	Stand Management Cooperative
TA	yr	Total age
TSCFV	ft^3 /ac	total stem cubic foot volume per acre